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ABSTRACT

This third in a series of ten modules for a course titled Welding Inspection presents the apparatus, process techniques, procedures, applications, associated defects, and inspection for the tungsten inert gas, metal inert gas, and submerged arc welding processes. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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NUCLEAR TECHNOLOGY

COURSE 28 WELDING INSPECTION

MODULE 28-3 Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding

CE 024 263

GENERAL PHYSICS CORPORATION
Columbia, Maryland

COURSE MODULES

COURSE 28 WELDING INSPECTION

Module 28-1 Welding Fundamentals and Processes

Module 28-2 Shielded Metal Arc and Oxyacetylene Welding

Module 28-3 Tungsten Inert Gas (TIG), Metal Inert Gas (MIG) and Submerged Arc Welding

Module 28-4 Weld Joint Verification

Module 28-5 Qualifications

Module 28-6 Process Controls

Module 28-7 Acceptance Inspection

Module 28-8 Filler Metal Control

Module 28-9 Weld Repair Control

Module 28-10 Records

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This module was prepared for General Physics Corporation by John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

The Nuclear QA/QC Technician monitors welding operations and inspects completed welds. In addition, the technician determines if correct welding procedures are in use and that the assigned welders are properly qualified. In carrying out these tasks, the technician relies upon knowledge of welding technology as well as written procedures and instructions. This module describes the technology associated with the tungsten inert gas, metal inert gas, and submerged arc welding processes.

Tungsten inert gas, metal inert gas and submerged arc welding processes are readily automated and offer a wide range of welding speeds and depth of base metal melting. While the equipment is somewhat expensive, lower welding costs may be realized due to their higher welding speeds, as compared to oxyacetylene and shielded metal arc welding.

The tungsten inert gas welding process enjoys the most versatility, but has the slowest welding speed of these three processes. It can be used with all types of metals and in all positions. It offers excellent control of heating rate and resultant base metal penetration.

The metal inert gas welding process offers much higher welding speeds and it is suitable for welding all types of materials in all positions. Highest welding speeds are attainable in the flat and horizontal positions.

Submerged arc welding has the largest range of selection of weld bead size and penetration depth. It is employed primarily in welding low carbon and low alloy steels and for hard-surfacing. Its welding speed is unsurpassed by any of the other welding processes covered in this course, but flat or horizontal positions must be used.

This module describes the key features of each of these welding processes. It presents the apparatus, process techniques, procedures, applications, associated defects and

inspections for each process. The student/trainee should approach this module from the viewpoint of how each welding process makes (or fails to make) a sound weld. It will become evident that each process contains key features which if employed properly can produce high quality weldments.

Knowledge of the welding processes presented in this module should equip the student/trainee to understand the basis for qualifications, process controls and inspection requirements presented in later modules of this course.

MODULE PREREQUISITES

Prior to commencing study of this module, the student/trainee should have prior training or experience in welding fundamentals, oxyacetylene welding and shielded metal arc welding.

OBJECTIVES

Upon completion of this module, the student/trainee can:

1. Label sketches of equipment to name the major components for TIG, MIG and SAW welding processes.
2. Describe the functions of major components of the equipment used in TIG, MIG and SAW welding processes.
3. State the effect on TIG, MIG, and SAW welding processes of changes in procedure variables including voltage, current, feed rate, and travel speed.

4. Describe the shielding employed with TIG, MIG and SAW welding processes.
5. Name and describe the three methods of metal transfer in the MIG welding process.
6. Name at least one potential cause for given weld defects in any of the TIG, MIG and SAW welding processes.
7. Name three functions of the flux used in SAW welding processes.
8. Name two typical applications each of the TIG, MIG and SAW welding processes and describe the features of the process which make it suitable for the named application.

TUNGSTEN INERT GAS WELDING PROCESS

Description of Process

The tungsten inert gas welding process uses a non-melting tungsten electrode. The welding arc is struck between the electrode and the work piece and produces the heat necessary for welding. A forced flow of inert gas shields the end of the electrode, the arc, and the molten weld puddle from the atmosphere. Filler material is added separately into the arc.

Equipment

The tungsten inert gas (TIG) welding process employs a nonconsumable electrode, electrode holder (torch), electrical power supply and a shielding gas supply as shown in Figure 28-3-1.

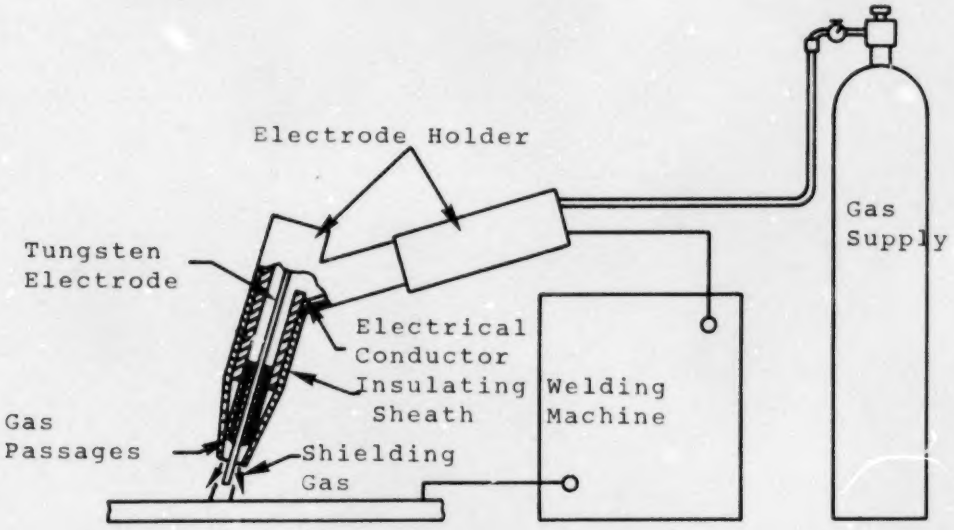

Figure 28-3-1
Schematic Diagram of Gas Tungsten-Arc Equipment

The electrode may be pure tungsten or a tungsten-alloy. Tungsten alloy electrodes contain one or two percent thorium or zirconium to improve arc initiation and stabilization. The electrodes range in diameter from .020 inch to .250 inch and are about seven inches long. The electrode diameter is selected to correspond to the welding current to provide the desired current density at the tip.

The torch receives the electrical power supply cable and the shield gas hose. Electrical power is conducted to the electrode and the shielding gas is routed around the electrode. A shielding gas cup surrounds the electrode and channels gas flow to displace the atmosphere around the arc. The electrode sticks out slightly past the shield gas cup to permit arc initiation. Some TIG torches are equipped to be water cooled.

The electrical power supply provides direct or alternating current. Power supplies used for SMA welding may be used for TIG welding or power supplies may be designed specifically for use with TIG welding. Power supplies designed for TIG welding are equipped with automatic means for controlling gas and water flow at the start and stop of welding. A high frequency current is often superimposed for arc initiation and stabilization.

Argon or helium is normally the shielding gas, although an argon/helium mixture is occasionally used. These inert gasses do not combine with other elements and are relatively insoluble in molten metals. Gas purity is normally 99.95 percent or more to insure excellent shielding.

Process Techniques

The TIG process requires some preliminary means of initiating emission of electrons and ionization of shielding gas. The arc can be initiated by touching the electrode to the work piece or to a copper starting block and quickly

withdrawing it to form an arc. Another means is high frequency arc initiation. Use of the high frequency spark or the copper starting block eliminates the chance of breaking off the tip of the electrode and imbedding it in the weld.

In the TIG welding arc, the negative ions (electrons) have more effect than the positive ions, apparently due to the high speeds acquired by the electrons in moving through the arc. For this reason, straight polarity is preferred whenever direct current is used. With straight polarity, the electrons emitted from the negative electrode are accelerated by arc voltage and strike the positive work piece at high speeds. This direction of electron flow results in the majority (about 2/3) of arc energy being deposited in the base metal. If reversed polarity is used, electrons striking the electrode result in the majority of arc energy being deposited in the electrode with less penetration in the work piece.

Argon requires less arc voltage than helium to sustain the arc and it gives a smoother, quieter arc. These properties make argon especially suited for TIG welding of thin parts and for welding in the overhead and vertical positions. On the other hand, the higher arc voltage of helium is desirable for welding thick joints. Also, the higher arc energy of helium permits higher welding speeds. Where a balance of characteristics is desired, a mixture of argon and helium is used.

The flow of gas around the electrode shields the molten weld puddle from the atmosphere. The gas cup and the heat from the arc give about the same gas flow pattern, whether argon or helium is used. However, slightly higher flow rates are needed with helium for good shielding due to helium's lower atomic weight.

Continuous current or pulsed current may be used for

TIG welding. Pulsed current permits higher instantaneous arc energy, which rapidly melts base metal and filler material during the pulse. Between pulses of current, no heat is applied. The net result is deeper melting but smaller aggregate size of molten weld metal. Advantages of pulsed current are:

- increased depth to width ratio of weld beads - This ratio increases with decreases in pulse duration coupled with increases in current value.
- elimination of burn through - Complete melting of the root will occur but the molten weld puddle is too small to fall away.
- minimal heat affected zone - Dissipation of heat between pulses reduces the volume of base metal whose properties are affected by heat from welding.
- agitation of the weld puddle - Electromagnetic forces tend to agitate the weld puddle. These forces are larger because of the large current value associated with pulsed current. Agitation of the weld puddle reduces the chances of porosity and incomplete fusion.

If filler material is needed, straight length of spooled bare rod is used. Best control of weld puddle flow is normally obtained with the forehand technique. Automated TIG welding uses spooled bare rod to permit continuous feed of filler materials into the arc. As with other arc welding processes, the filler material feed rate must be compatible with the arc energy available for melting the filler material.

Unique Techniques

Automated TIG welding machines may be set for stringer bead or weave bead techniques. When employing the weave bead technique, equipment oscillation controls are adjusted for desired oscillation width, frequency and dwell time.

(Dwell time refers to time of no lateral movement of the torch at either extreme of bead width.) Dwell time permits longitudinal progression of the torch (or work piece), such that the next oscillation provides proper bead overlap at the extremes of the weld bead width.

Procedure Variables

Welding procedures for the tungsten inert gas welding process cover the variables listed in Table 28-3-1. Procedures will specify specific values for each variable listed.

The procedure variables listed in Table 28-3-1 are divided into essential and nonessential variables using the same rationale as used for other welding processes. That is, essential variables are those so important as to require procedure requalification when any essential variable is changed beyond limits specified by the applicable welding code. Values for nonessential variables must be provided to the welder but those values can be changed by engineering without requalifying the procedure.

The TIG process may employ multiple electrodes. Each TIG welding procedure should identify the type of electrode (e.g., tungsten, tungsten-thorium), the number and spacing of electrodes and the length of electrode extension beyond the face of the gas cup. The procedure may also specify the electrode tip preparation and the frequency of repreparing the electrode tip.

While the procedure should cover initial and interpass cleaning, little interpass cleaning is necessary with TIG welding. There is no slag and, if shielding is good, no oxides.

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FUNCTIONAL VARIABLES	ESSENTIAL VARIABLE	NONESSENTIAL VARIABLE
Joint Design	None	(a) groove type and design (b) use of backing
Base Metals	(a) material type (b) joint thickness	None
Filler Material	(a) type of material (b) Chemical composition of weld metal (c) use of consumable inserts	(a) diameter of filler (b) electrode type and diameter
Position	(a) where impact properties are tested, the welding position to be used	(a) for all other applications the welding position to be used
Preheat	(a) decrease of more than 100 F in minimum preheat temperature from that qualified (b) where impact properties are tested, an increase in specified maximum interpass temperature	(a) minimum preheat temperature (b) maximum interpass temperature
Post Weld Heat Treatment	(a) heat treatment temperature and time	None
Gas	(a) type of shielding gas	(a) gas flow rate (b) use of gas backing
Electrical Characteristics	(a) where impact properties are tested, type of current and voltage	(a) where impact properties are not tested, type of current and polarity and value of current and voltage
Technique	(a) where impact properties are tested, oscillation width, frequency and dwell time; number of passes and of single or multiple electrodes; and vertical progression	(a) use of oscillation and oscillation settings (b) gas cup size (c) method of initial and interpass cleaning (d) method of back gouging (e) number of passes (f) number of electrodes (g) use of nonmetallic retainers (h) electrode spacing (i) vertical progression (j) manual or automatic

Application

Tungsten inert gas is a very versatile welding process that can be used for all alloys and in all positions. It is very capable of producing welds free of porosity and oxides or nitrides. It offers excellent control of welding heat, depth of penetration, and weld bead shape. There is no spatter or slag. TIG weld bead surfaces are relatively smooth and uniform. Therefore, manual and automatic TIG weld bead surfaces are relatively smooth and uniform. Therefore, manual and automatic TIG welding have a wide variety of applications.

TIG is particularly useful for welding very thin parts and root passes of thicker parts. Its precise heat control permits such application without risk of burnthrough and there is no slag to be trapped in root areas. When finish of the as-welded bead surface is important, TIG makes an excellent selection of welding processes.

The main drawback of TIG welding is its relatively slow welding speed. Therefore, it is not frequently used for welding heavy gauge materials (except for root passes).

Characteristic Defects, Causes and Detection

Tungsten inert gas welding can produce the defects listed in Table 28-3-2.

As shown in Table 28-3-2, the causes of porosity are mostly associated with inadequate shielding. In addition to improper shield gas flow, arc wander can cause porosity in TIG welding. Electromagnetic forces generated by current can divert the arc momentarily or continuously. This phenomenon stems from a physical law that charged particles moving through a magnetic field will tend to go in a direction at right angles to the magnetic field. Weld joint configurations and residual magnetism can cause

the arc to see differing magnetic fields as weld progression occurs and the arc will wander. The welder will notice arc wander and eliminate it by shifting the ground cable connection or demagnitizing the work piece. Where the arc has wandered outside the shielding gas envelope, porosity will occur and the welder should grind such areas to sound metal.

Arc wander can also cause incomplete fusion because the heat is diverted from the desired area. Again, the welder should notice arc wander and grind as necessary to avoid incomplete penetration in the final weld.

When tungsten inclusions are found in the weld, the obvious source is the TIG electrode. The electrode has been struck on the work piece or dipped into the weld puddle or melted from excessively high current. When the welder notices dipping of the electrode, welding should be stopped and the area should be ground.

Weld metal cracks can be caused by using incorrect base or filler material and by incorrect weld bead shape. As the weld bead solidifies, shrinkage will cause surface tension if the bead is restrained from shrinking. As shown in Figure 28-3-2, concave beads place surfaces in tension while convex beads do not.

Weld metal cracks caused by concave weld beads can be avoided by proper combination of travel speed and filler material feed rate such that a slightly convex weld bead is produced.

Another area where weld bead convexity can cause cracking is at the point where welding of a bead is stopped. If the arc is rapidly withdrawn to extinguish welding, a weld bead crater results. The convex crater creates tension which tends to crack the weld metal. Such crater cracks are pictured in Figure 28-3-3.

Crater cracks can be avoided by a gradual withdrawal

Table 28-3-2

Characteristic Defects with TIG Welding

DEFECT	CAUSE	DETECTABLE BY
Porosity	(a) flow of shielding gas too low (b) flow of shielding gas too high such that turbulence draws in air (c) air drafts blowing shield gas away (d) gas supply hose, fittings or gas passages in torch are blocked (e) arc wander	(a) welder should notice black oxides forming (b) liquid penetrant for porosity open to survace (c) radiography for subsurface (d) welder should notice arc wander
Incomplete Fusion	(a) current too low (b) travel speed too high (c) filler material feed rate too high (d) arc wander	(a) welder should notice arc wander (b) radiography or ultrasonics
Tungsten Inclusion	(a) striking the arc on the work piece (b) dipping the electrode into the weld puddle (c) current too high for electrode diameter	(a) welder should notice deterioration of electrode tip (b) radiography
Weld Metal Crack	(a) incorrect base metal type (b) incorrect filler material type (c) concave weld bead (d) crater cracks	(a) liquid penetrant or magnetic particle for cracks open to surface (b) radiography or ultrasonics for subsurface cracks

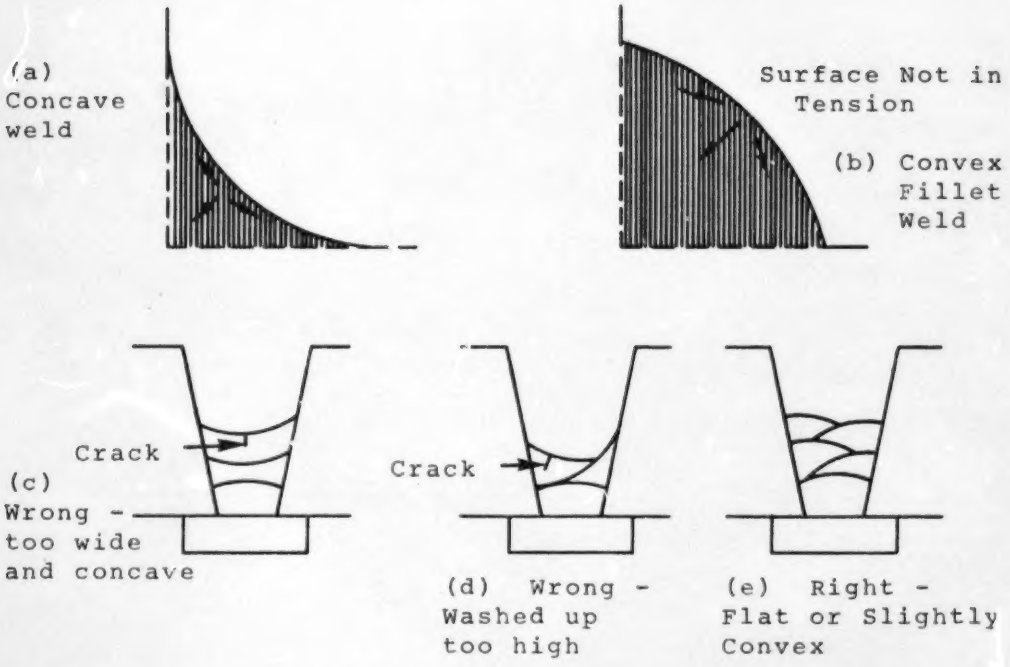

Figure 28-3-2
Concave and Convex Weld Beads

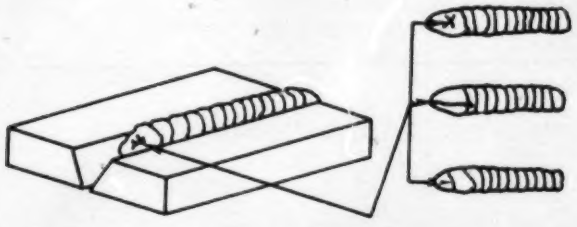

Figure 28-3-3
Crater Cracks

of the arc with sufficient filler material addition to fill up the crater. In this manner, the welding stop is convex rather than concave. Just to make sure there will be no crater cracks in the final weld, welders often grind each stop to remove the crater. It is noted that crater cracks can also occur with any welding process.

METAL INERT GAS WELDING PROCESS

Description of Process

Metal inert gas welding (MIG) is a process that produces fusion by heating with an electric arc between a consumable electrode and the work piece. Shielding is provided by gas flow around the consumable electrode. Fill material is provided by the consumable electrode.

Equipment

Four basic components comprise the metal inert gas welding equipment: welding torch or gun, wire feeder and wire supply, welding power source, and shielding gas supply. These components are schematically pictured in Figure 28-3-4.

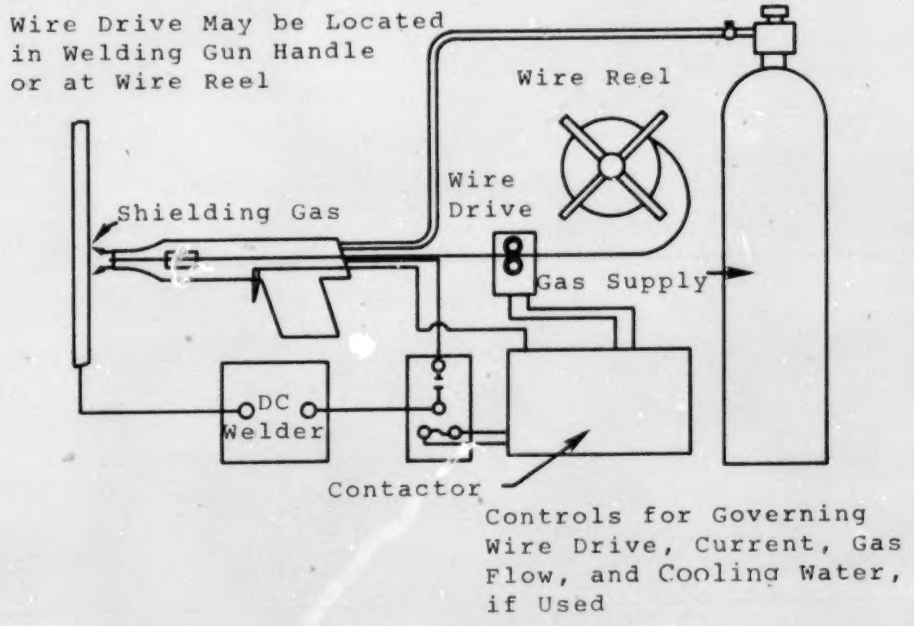
Wire Drive May be Located in Welding Gun Handle or at Wire Reel
Wire Reel
Wire Drive
Shielding Gas
Gas Supply
DC Welder
Contactor
Controls for Governing Wire Drive, Current, Gas Flow, and Cooling Water, if Used

Figure 28-3-4
Schematic Diagram of Gas Metal-Arc Welding Process

Electrical contact with the bare filler wire is made in the torch such that the filler wire becomes a consumable electrode. Shielding gas enters the torch and envelopes

the wire as it exits. The bare filler wire is melted by the electric arc at a rate equal to the feed rate. If the torch is operating at over 200 amps it is normally water cooled.

The torch is adaptable to automatic welding or manual semi-automatic welding. In automatic MIG welding, a central panel controls the entire welding sequence. The central control panel (1) initiates gas flow, cooling water flow, wire feed and travel carriage speed, (2) maintains arc length, current, travel speed, gas flow, etc., to keep stable welding conditions during the welding cycle, (3) stops travel carriage; starts crater fill; stops welding current, gas flow and cooling water, and (4) returns carriage to starting position.

In manual semi-automatic MIG welding, a hand held torch employs a trigger switch to activate welding. It may or may not be water cooled. Some manual torches have an integral wire drive which "pulls" the wire. Use of a "pull" gun with a remote wire feeder permits welding with very fine wires.

Spooled bare rod is fed by a motorized wire feeder. The wire feeder may be separated from the torch or integral with it. Rollers and guide tubes keep a straight feed through the torch. The spooled wire may be solid or flux-cored.

Direct current power supplies are designed specifically for MIG welding. Early versions of MIG power supplies work on a constant current principle. With these power supplies, voltage varies inversely with changes in current. For a given current setting, if wire feed rate is slightly high, arc length is decreasing which decreases voltage. The voltage decrease is sensed by the wire feeder and the feed rate is automatically slowed. If feed rate is too slow, arc length is increasing which raises voltage. The wire feed

sensor detects the voltage increase and increases feed rate. In later MIG power supply designs, constant or rising voltage principles are employed. The wire feeder maintains a preset speed and arc length is controlled by the power supply. If arc length decreases, the current output of the power supply increases to maintain constant (or rising) arc voltage. The increased current melts the wire at a faster rate which increases arc length. As arc length increases, current decreases to maintain constant (or decreasing) arc voltage. Decreased current lowers the melting rate of the filler wire.

Argon or helium shielding gas is used for MIG welding of aluminum, copper, titanium, magnesium, and zirconium alloys. For low carbon and low alloy steels, either carbon dioxide or argon with up to 5% oxygen is used.

The MIG welding process can employ either of two methods of transferring filler material into the weld puddle: arc metal transfer or short circuiting transfer. Arc metal transfer may be by a spray of very fine droplets or by globular droplets.

Spray Arc Transfer Technique

In the spray arc transfer method, very tiny droplets of molten filler material travel across the arc from the bare wire electrode to the work piece. As bare wire is fed into the arc, the arc energy melts the wire at a rate which keeps arc length essentially constant and keeps a continuous spray of filler material droplets. Electron and gas ion flow is the same as in tungsten inert gas welding (TIG). Unlike the TIG process, however, the MIG electrode is constantly spraying droplets into the weld puddle and there is a reversal in the effects of polarity.

The positive gas ions give the largest effect in the MIG spray arc transfer method. With direct current straight

polarity, positive ions move toward the negative electrode and against the spray of droplets. Consequently, the droplets are slightly larger before being released into the arc stream and they strike the work piece with less velocity and penetrating power. With direct current, reversed polarity, the positive gas ions move toward the negative work piece and with the spray of droplets. Consequently, smaller droplets are released and gain more speed in traversing the arc and strike the weld puddle with more penetrating power. The spray arc transfer method works best on direct current reversed polarity.

The MIG spray arc transfer process was initially developed in welding of aluminum alloys using argon or helium shielding gas. But when this process was applied to steels, considerable arc wander deteriorated the stable conical arc spray pattern associated with aluminum welding. Apparently, oxides on steel surfaces gave resistance to arc penetration and the arc wandered in search for the easiest path of penetration. Undercut and porosity resulted.

MIG spray arc has been quite successfully applied to welding of steels by adding small quantities of oxygen or carbon dioxide to argon. Addition of these oxidizing agents produce a fairly uniformly oxidized surface such that the arc becomes anchored in the immediate vicinity of the arc crater. Since the oxidizing agents can cause porosity and scavenge some of the alloy ingredients of the base metal and filler material, deoxidizers and/or alloying ingredients need to be added. Consequently, filler wires containing deoxidizers are used for MIG welding of steels.

Shielding with 100% carbon dioxide in MIG welding of steels permits higher welding speeds and greater penetration. The chief drawback to use of this less expensive gas is a rather harsh arc and considerable spatter. These drawbacks are overcome by using filler wire containing deoxidizers and

addition of fluxes. Flux can be added in the form of magnetic powders which are attracted to the wire in the torch and form a thin coating that is carried into the arc. A more popular method is flux-cored wire where tubular wire is filled with flux. In either case, the flux contains deoxidizers to minimize porosity and allow metals to achieve desired weld metal chemistry.

Globular Arc Transfer Technique

If the high current density needed for spray arc metal transfer is reduced, an abrupt change in the transfer mode occurs at some point designated as the transition current. For a given diameter electrode operating in the spray arc mode and as current is decreased, the size of the tiny droplets gradually increases and the number of drops per second gradually decreases. At the critical current, the droplets suddenly become much larger and drop much less frequently. This is illustrated for mild steel in Figure 28-3-5.

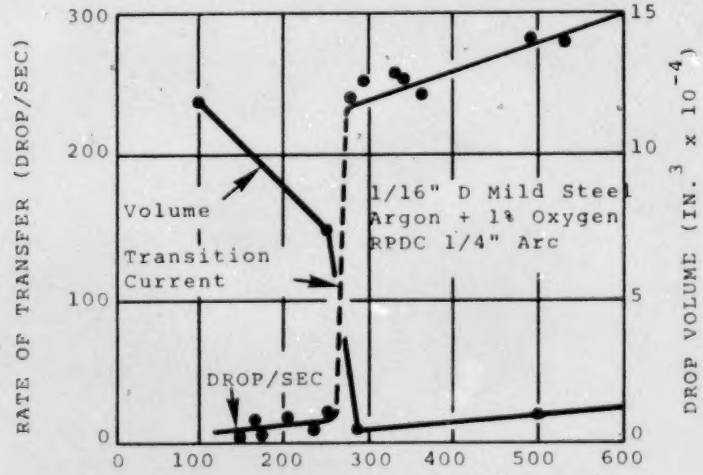

Figure 28-3-5

Graph showing relationship of amperage to droplet transfer rate and drop size for welding with 1/16 in. dia. steel wire and argon shielding.

The curves in Figure 28-3-5 illustrate for this case tnat, as current decreases from 265 amperes to 255 amperes, the drop size increases from .04 inch to .16 inch and the drop rate decreases from 240 drops per second to 15 drops per second. The median current at which these abrupt changes occur is 260 amperes which is the transition current value in this case. The same transition phenomenon occurs with all metals but at different levels of current. However, the electrode melting rate does not abruptly change but follows the expected change proportional to the change in current.

Below the transition current globular metal arc transfer occurs. Since there are insufficient forces within the arc to "jet" spray the filler metal, a ball of molten filler metal hangs to the electrode tip until it is large enough to be pulled away by gravity. Globules larger in diameter than the wire diameter are not uncommon.

Globular arc transfer gives less penetration than spray arc transfer and causes arc turbulence and weld spatter. Accordingly, spray arc transfer is more commonly used.

Short Circuiting Metal Transfer Technique

Short circuiting metal transfer occurs by frequently dipping the electrode into the weld puddle. This method operates with current values well below the transition current and it requires special circuits in the power supply to limit short circuiting current slope and peak. The short circuiting method is illustrated in Figure 28-3-6.

Starting with the electrode shorted to the weld puddle in Figure 28-3-6, the arc is extinguished and a surge of current is caused by the short circuit. The power supply limits the rate of current increase and the current peak to avoid overloading the electrical circuitry. When the electrode withdraws from the puddle, ample current flow exists

to recreate the arc. Heat from the arc forms a globule on the wire tip by the time the wire again dips into the weld puddle starting the cycle again. All filler metal transfer occurs when the arc is extinguished during the short circuit which is occuring at a steady frequency anywhere from 20 to over 200 times per second. The net result is a very stable arc of low energy and heat input. Short circuiting metal transfer produces a relatively small weld puddle and much less penetration as compared to spray arc transfer. Any of the shielding gases used with spray arc may be used.

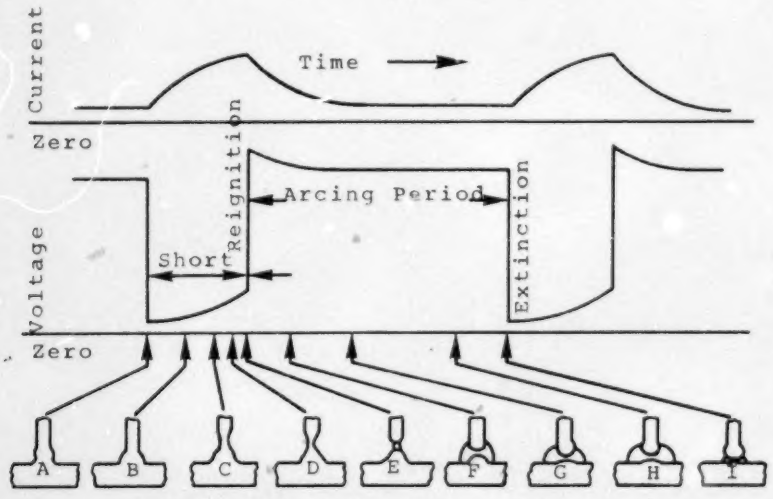

Figure 28-3-6

Oscillograms and Sketches of Short Circuiting Arc Metal Transfer

Procedures

Metal inert gas welding procedures should cover the variables listed in Table 28-3-3. Procedures specify specific values for each variable listed.

The rationale for differentation of essential and non-essential variables is the same as that described for the TIG welding process.

As with tungsten inert gas welding, the MIG welding process can employ multiple electrodes and oscillation

controls. The welding procedure will specify the various equipment settings needed for automatic or manual welding. Most welders make it a standard practice to check the operation of the equipment by welding a small test piece prior to commencing production welding. This helps to assure proper alignment and setting of variables.

Application

Metal inert gas welding is suitable for all types of base metals. The various methods of filler metal transfer permit MIG welding in all positions.

Spray arc MIG welding gives deep penetration and it offers welding speeds four or more times the speed of shielded metal arc welding. Travel speeds of 30 inches per minute and deposition rates of 20 pounds per hour are not uncommon. Therefore, spray arc MIG welding is frequently employed where large volumes of filler metal is needed to complete the weld. Due to the relatively large size of the molten weld puddle, spray arc is suited for flat and horizontal positions.

Short circuiting metal transfer permits MIG welding to be accomplished in the vertical and overhead positions due to the smaller molten weld puddle associated with this method. Also, it is used for welding thin materials since its lower heating rate eliminates burnthrough that would occur with spray arc.

Characteristic Defects, Their Causes and Detection

Characteristic defects, their causes and means of detection for MIG welding are given in Table 28-3-4.

Defect prevention with MIG welding primarily rests with obtaining the correct combination of weld metal deposition rate and travel speed. Current values needed for MIG welding are dependent on diameter of bare filler

Table 28-3-3
Procedure Variables for Metal
Inert Gas Welding

FUNDAMENTAL VARIABLES	ESSENTIAL VARIABLE	NONESSENTIAL VARIABLE
Weld Joint	None	(a) groove type and design (b) use of backing
Base Metals	(a) material type (b) joint thickness	None
Filler Material	(a) type of material (b) chemical composition of weld material (c) whether bare solid wire or bar flux-cored wire	(a) diameter of wire
Position	(a) where impact properties are tested, vertical progressing if vertical position is used	(a) the welding position to be used
Preheat	(a) decrease of more than 100 F in minimum preheat temperature from that qualified	(a) minimum preheat temperature (b) maximum interpass temperature (c) whether preheat is to be maintained for stress relieve furnace
Post Weld Heat Treatment	(a) heat treatment time and temperature	None
Gas	(a) A change in type of shielding gas or gas mixture	(a) type of shielding or gas mixture (b) gas flow rate (c) use of gas backing
Electrical Characteristics	(a) where impact properties are tested, the type and polarity of current and values for voltage and current	(a) current type and polarity (b) current and voltage values (c) type of power supply (d) method of metal transfer
Technique	Where impact properties are tested: (a) width, frequency and dwell time of oscillation control (b) angles of passes (c) number of electrodes (d) vertical progression	(a) whether stringer or weave bead (b) method of initial and interpass cleaning (c) method of back gouging (d) oscillation settings of width, frequency and dwell time (e) number of passes (f) number of electrodes (g) use of nonmetallic retainers (h) electrode spacing (i) vertical progression (j) whether manual or automatic

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Table 28-3-4
Characteristic Defects with MIG Welding

DEFECT	CAUSE	DETECTABLE BY
Undercut	insufficient number of passes; excessive current on last pass causing excessive melting of toe	visual inspection or radiography
Burnthrough	excessive current; travel speed too slow	visual inspection or radiography
Porosity	low gas flow; air drafts; excessive gas flow whose turbulence draws in air; failure to use deoxidizers with reactive shielding	liquid penetrant for porosity open to surface; radiography
Incomplete Fusion	incorrect bead sequence; incorrect torch oscillation; current too low; travel speed too high	radiography or ultrasonic
Crack in the Weld Metal	incorrect base metal; incorrect filler wire; preheat too low; concave beads; excessive current; crater cracks	liquid penetrant or magnetic particle for surface; radiography or ultrasonic for subsurface
Underbead Crack	preheat too low; excessive current	radiography or ultrasonic
Spatter	occurs with spray arc and globular transfer; excess spatter can be caused by excess voltage or arc length	visual inspection or radiography

wire and wire feed rate. Travel speed determines bead shape for a given feed rate. These three variables (current, feed rate, travel speed) establish the heating rate at the point of welding. Excessive heating rates give potential for burnthrough on early passes and weld metal and underbead cracking on any pass. Welding root passes by short circuiting transfer or by another process, e.g., TIG, eliminates potential for burnthrough. Proper heating rate and control of preheat and interpass temperatures can eliminate weld metal and underbead cracking.

Some amount of fine porosity normally occurs with MIG welding. The high welding speed makes it virtually impossible to provide perfect shielding. Many applications are not adversely affected by fine porosity. Where fine porosity must be eliminated, MIG welding equipment is placed in a welding chamber which is evacuated and then filled with inert gas, e.g., argon.

SUBMERGED ARC WELDING PROCESS

Description of Process

Submerged arc welding is a process where heat for fusion is produced by an electric arc between a bare wire consumable electrode and the work piece. Shielding is provided by a blanket of granular, fusible flux which completely inundates the arc. Filler material is provided by the consumable electrode.

Equipment

The submerged arc welding process employs a welding head, bare filler wire, granular flux and electrical power supply as illustrated in Figure 28-3-7.

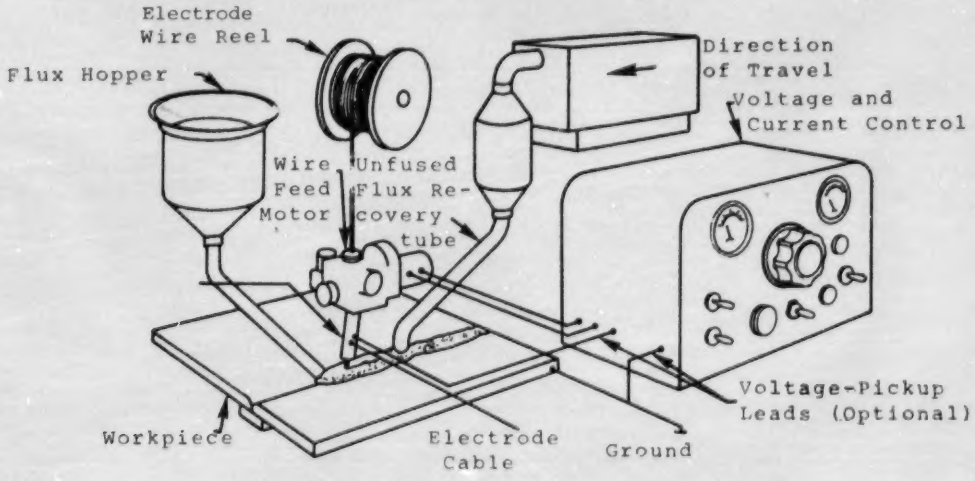

Figure 28-3-7
Essential Components of a Typical Machine
for Automatic Submerged-Arc Welding

Both automatic and semi-automatic submerged arc welding heads are available. An automatic head consists of a motor driven electrode feeder along with necessary electrical connections to introduce the welding current into the electrode.

The wire feeder may be reversing or nonreversing. The automatic head mounting arrangement contains positioning and tracking adjustments to permit locating and holding the arc at the desired location. The positioning equipment may traverse the head along the weld joint or it may hold the head while the weld joint is traversed under it. In either case, precise control of arc location needs to be maintained.

Semi-automatic heads are portable and consist of a small conical flux hopper positioned concentrically about the electrode nozzle tip with a handle attached so that it can be held and manipulated manually. The electrode feeding device is a separate unit which feeds the electrode through flexible tubing to the handle butt. The electrode progresses through the handle to the nozzle assembly which contains electrical connections to introduce current into the electrode.

Straight length or spooled bare wire can be used for filler material. Spooled bare wire is mostly used to take advantage of the high welding speeds attainable with submerged arc welding. Most straight length bare rod applications involve hard surfacing where the low ductility of the hard surfacing filler alloy does not permit spooling. The filler material serves as the electrode and is consumed at a rate equal to the feed rate.

Granular fusible flux provides shielding. It can be manually poured onto the weld joint but normally is automatically fed ahead of the arc from flux hoppers. Sufficient flux is used to completely bury the arc and the resultant weld bead. Submerged arc welding is one of the few welding processes not requiring eye protection other than routing safety glasses for normal eye protection.

Either direct current or alternating current electrical power supplies can be used. They may be constant current types or constant voltage types. As with the MIG process,

constant current type power supplies must be used with wire feeders that sense voltage and adjust wire feed rate to maintain proper arc length. Constant voltage types are used with fixed wire feed rates and the power supply adjusts current to maintain proper arc length. At very high welding currents with direct current power supplies, arc blow (wander) becomes a problem due to the associated magnetic fields. Also, if two or more electrodes are employed, no more than one electrode is fed by direct current. Otherwise, the arcs attract or repel each other depending on polarity causing uncontrollable arc wander.

Process Techniques

Prior to arc initiation, flux is preplaced, manually or automatically, so that the entire area surrounding the electrode tip is covered with flux. As welding progresses, flux is added (or has been preplaced) to keep the electrode tip totally submerged. If any sparking is visible, there is not enough flux and more is added.

The arc is initiated by one of several methods. A small ball of steel wool can be placed between the end of the electrode and the work piece to provide short circuiting current path. When current is applied, the steel wool rapidly melts, thereby, creating an arc. This method is used with non-reversible wire feeders. If the wire feeder is reversible, the wire can be prepositioned against the work piece. When current is applied, momentary reversal of wire feed will generate the arc. Scratch starting places the electrode against the work piece, starts travel of the head and wire feed and then applies current. Another method is high frequency current which ionizes the air between the electrode and the work piece to initiate the arc.

Once the arc is initiated, the heat melts the base metal, the electrode, and the granular flux. Since molten flux is much less dense than molten weld metal, it floats on the weld puddle. This molten flux shields the molten weld metal and helps to stabilize the arc. As welding progresses, the trailing edge of the molten flux solidifies forming an adherent slag covering over the solidified weld bead. In this manner, no air can come into contact with the molten weld puddle or the hot weld bead as can be seen in Figure 28-3-8.

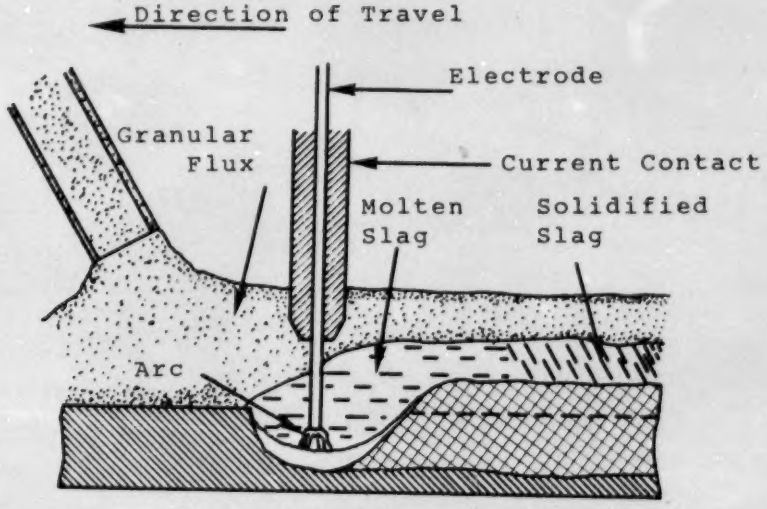

Figure 28-3-8
Diagrammatic Sketch of Submerged Arc Welding Operation on Heavy Plate

As shown in Figure 28-3-8, sufficient flux is used such that excess flux that is still granular remains on top of the slag. This excess flux can be collected by an industrial vacuum machine as shown in Figure 28-3-7. The collected excess flux can be reused provided it is kept clean and dry. After removing the excess flux and after some cooling of the weld bead, the slag must be removed prior to welding the next pass. A manual slag pick will normally

remove the slag although some grinding may be needed along the edges of the bead.

In addition to generating slag, fluxes affect the weld metal chemistry to an extent determined by the exact constituents of the flux. Certain fluxes contain predetermined amounts of deoxidizing and alloying ingredients which help achieve the desired weld metal chemistry. These deoxidizing and alloying ingredients are selected based on achieving a desired weld metal chemistry with a known base metal and filler material composition. Other fluxes do not have alloying ingredients but, nonetheless, affect weld metal chemistry at least slightly because no flux is completely non-reactive.

The high current densities employed with submerged arc welding generate considerable heat. The relative amounts of melting of base metal (penetration), filler material (deposition rate), and flux by this heat are determined by several variables selected to give penetration ranging from deep penetration to very shallow penetration.

The type and polarity of current affect penetration and deposition rate. Direct current reversed polarity gives greatest penetration with a corresponding lower deposition rate. Straight polarity gives lower penetration and higher deposition. Alternating current gives penetration and deposition somewhere between direct current reversed polarity and direct current straight polarity.

Current affects penetration and deposition rate. Penetration is proportional to the absolute value of current, i.e., higher current gives deeper penetration and lower current gives shallower penetration. The current density (absolute value divided by cross-sectional area of electrode) directly affects deposition rate. If wire diameter is decreased with a constant current value, deposition rate increases but penetration is unaffected.

Electrode extension or stick out (distance from nozzle tip to electrode tip) affects deposition rate. With all other variables held constant, increasing electrode extension will increase deposition rate and decrease flux consumption and penetration. Since the wire may curl and cause arc wander as electrode extension is increased, wire straighteners are normally integral with the wire feeder mechanism.

Arc voltage has great effect on bead shape and contour but very little effect on penetration. Low voltage results in narrow, rough, bumpy weld beads. High voltage produces broad, flatter beads which may roll over and have incomplete fusion at the edges. Arc voltage also directly affects the amount of flux that melts. Higher voltage will consume more flux.

Travel speed affects bead size and shape. Fast speeds produce narrow beads with penetration restricted to the area close to the electrode position. Slow travel speed produces wider beads with uniform penetration for a considerable distance on either side of the electrode position.

Procedure

Submerged arc welding procedures need to cover the variables listed in Table 28-3-5. Procedures specify specific values for each variable listed.

The rationale for differentation of essential and non-essential variables is the same as that for the TIG welding process.

Flux classification becomes an essential variable because weld metal chemistry is affected, at least slightly, by the flux constituents. Manufacturers of the flux normally hold proprietary the flux composition and flux manufacturing processes but publish data identifying usable flux classifications for various base metal and filler

Table 28-3-5
Procedure Variables for Submerged Arc Welding

FUNDAMENTAL VARIABLES	ESSENTIAL VARIABLES	NONESSENTIAL VARIABLES
Joint Design	None	(a) groove type and design (b) use of backing
Base Metal	(a) material type (b) joint thickness	None
Filler Material	(a) filler material type (b) deposited weld metal chemical composition (c) flux classification	(a) diameter of electrode
Position	None	(a) the welding position to be used
Preheat	(a) a decrease of more than 100°F in specified minimum preheat temperature from that qualified (b) an increase in specified maximum interpass temperature	(a) the minimum preheat temperature (b) whether preheat is to be maintained to post weld heat treatment furnace (c) the maximum interpass temperature
Post Weld Heat Treatment	(a) heat treatment temperature and time	None
Electrical Characteristics	(a) where impact properties are tested, a change in oscillation settings, multipass to single pass, number of electrodes	(a) type of current and polarity (b) current and voltage values
Technique	(a) where impact properties are tested, the type of current and polarity and the amperage and voltage	(a) stringer or weave bead (b) method of initial and interpass cleaning (c) method of back gouging (d) oscillation width, frequency and dwell time (e) number of passes and sequence (f) number of electrodes and electrode spacing (g) use of nonmetallic retainers

material combinations. The data are based on chemically testing the weld metal composition of weld metal test plates welded by submerged arc. Similar test plates are welded by the submerged arc procedure at the job site and chemically tested to confirm correct weld metal composition.

The flat position is best for submerged arc welding due to the large size of molten weld and slag. Horizontal position can be used but coffer dams may be needed to retain the flux. Submerged arc welding is not suitable for overhead and vertical positions.

As with the MIG welding process, multiple electrodes may be used. Also, a "cold" wire (no electrical energy applied) may be fed into the arc generated by the "hot" wire. Either of these techniques increases the deposition rate.

Automatic submerged arc welding equipment normally has oscillation controls to adjust for stringer or weave bead. As with MIG welding, width, frequency and dwell time are adjustable.

Large quantities of slag are produced by submerged arc welding. This slag must be removed after each pass to prevent it being entrapped by subsequent passes.

Welding head tracking is very important. The welder cannot see exactly where the arc is tracking because it is submerged. To ensure proper tracking, automatic submerged arc equipment is carefully prealigned prior to commencing welding. The welder aligns the equipment and traverses the head without starting current or flux. In this manner, the precise path of the electrode can be fixed.

Application

Submerged arc welding is used primarily for welding of ferrous alloys although it is adaptable to other alloys such as nickel-copper. Its capability of adjusting for deep or

shallow penetration and its high welding speed makes it beneficial for joint welding and hardsurfacing.

For joints accessible for welding both sides, full penetration can be achieved with a squared butt joint up to about 1 1/8 inches thick. For thicker joints, grooves are needed for full penetration but smaller included angles are possible due to the deep penetration attainable. Most fillet welds on tee joints can be made with one pass. With such ability to reduce weld preparation time and to offer high deposition rates, submerged arc welding is frequently employed where flat or horizontal positioning can be obtained.

For hardsurfacing, submerged arc welding variables are set for shallow penetration and high deposition rate. In this manner, base metal dillution of the weld metal may be from 10% to 20% and the desired surface hardness may be obtained in a single pass.

Characteristic Defects, Their Causes and Detection

Characteristic defects of the submerged arc welding process, their causes and means of detection are listed in Table 28-3-6.

As with the shielded metal arc welding process, interpass cleaning becomes very important to avoid slag inclusions. Large amounts of slag are produced by submerged arc welding which must be removed prior to welding the next pass.

If there is moisture in the granular flux, it decomposes to hydrogen and oxygen in the arc. Hydrogen can cause cracking in alloys subject to attack by hydrogen. Either gas can cause porosity. In order to avoid such problems, granular fluxes are dried by the manufacturers and packaged in vapor proof bags to keep them dry. As an added precaution, fluxes are often baked immediately prior to use.

Table 28-3-6
Characteristic Defects of the Submerged Arc Welding Process

DEFECT	CAUSE	DETECTABLE BY
Undercut	insufficient number of passes; excessive melting of base metal at toe of weld	visual inspection or radiography
Burnthrough	excessive current, insufficient travel speed	visual inspection or radiography
Incomplete Fusion	incorrect tracking of welding head; excessive voltage causing bead rollover; incorrect oscillation settings	radiography or ultrasonics
Crack in Weld Metal	incorrect base metal; incorrect filler material; preheat too low; moisture in flux	surface: liquid penetrant or magnetic particle subsurface: radiography or ultrasonic
Underbead Crack	preheat too low; excessive current; moisture in flux	radiography or ultrasonics
Slag Inclusion	inadequate interpass cleaning	radiography
Porosity	moisture in flux	radiography

Proper setting of electrical variables and adjustment of tracking controls can prevent burnthrough and incomplete fusion. In fact, submerged arc welding has the potential of producing excellent quality welds that are continuously defect free. If the flux is free of moisture and the weld joint is clean, there is essentially no chance or porosity. There is no weld spatter. All the other possible defects can be avoided by proper interpass cleaning and equipment settings.

EXERCISES

Review the information on Submerged Arc Welding Process by completing the following quiz:

Name the function(s) of the apparatus for submerged arc welding:

APPARATUS	FUNCTION
1. granular flux	a.
	b.
	c.
2. spooled bare wire	a.
	b.

Name the primary cause of the weld condition for submerged arc welding.

CONDITION	PRIMARY CAUSE
3. broad, flat bead that rolls over	

CONDITION	PRIMARY CAUSE
4. narrow, bumpy head	
5. burnthrough	
6. slag inclusion	
7. non-overlapping weave beads and incomplete fusion between weave beads	

Classify the statement as true or false for the submerged arc welding process.

8. Extremely high welding speed are obtainable in the flat position.
9. Deposition rate is a function of electrode extension past the welding head nozzle assembly.
10. Loss of argon flow causes porosity.
11. A wide range of penetration can be obtained by adjusting current, feed rate, and electrode extension.
12. This check list summarizes the major points of this module. Put a check by each point as you recall it.

    ____ The tungsten inert gas (TIG) welding process employs a nonconsumable electrode, electrode holder, electrical power supply and a shielding gas supply.

    ____ The material composition of TIG welding electrodes is pure tungsten, tungsten-thorium, or tungsten-zirconium. The latter two provide for higher current density capacity.

    ____ TIG welding may be performed with direct or alternating current. Direct current, straight polarity provides greatest penetration. Direct

current, reversed polarity provides least penetration.

____ Pulsed current in the TIG welding process provides for greater penetration with smaller aggregate size of the molten weld puddle. The pulsed current technique has the advantages of increased depth to width ratio of weld beads, elimination of burn-through, and minimal heat affected zone.

____ Argon, helium, or argon-helium mixture may be used for shielding in the TIG welding process. Argon provides for smoothest arc and helium provides for higher arc energy.

____ TIG welding is very versatile and may be used for all alloys and in all positions. It is particularly well suited for welding thin members, root passes, and joints in the overhead and vertical position.

____ The main drawback of TIG welding is its relatively slow welding speed as compared to metal inert gas and submerged arc welding.

____ Porosity in TIG welds is caused by inadequate shielding or arc wander.

____ Incomplete fusion in TIG welds is caused by insufficient current, excessive travel speed, excessive feed rate of filler material, or arc wander.

____ The most likely inclusion in TIG welds is a Tungsten inclusion because slag is not generated by this welding process.

____ Weld metal cracking in TIG welds may be caused by incorrect base metal type, incorrect filler material type, concave weld beads or craters.

____ The metal inert gas (MIG) welding process uses a consumable electrode, gas shielding, welding torch, wire feeder, and power supply.

____ Proper arc length in MIG welding is maintained by either of two methods. Either wire feed rate is automatically adjusted as arc voltage varies or current is automatically adjusted as arc length varies.

____ Spray arc transfer method provides for highest welding speed in MIG welding. In the spray arc method, tiny droplets of molten filler material are sprayed through the arc to the weld joint. In this method, direct current, reversed polarity gives greater penetration than direct current, straight polarity. This effect is caused by the positive gas ions either aiding or resisting the spray of droplets.

____ Below the transition current value, globular arc transfer occurs in MIG welding. Because this method gives less penetration and more arc turbulence and weld spatter, globular arc transfer is rarely used.

____ Short circuiting metal transfer provides for a very stable arc of low energy which is well suited for welding thin members and welding in the overhead and vertical positions. In this method, special current limiting devices in the power supply are necessary and all method transfer occurs during all metal transfer occurs during the short circuit.

____ MIG welding uses argon, helium, argon-oxygen, argon-carbon dioxide or pure carbon dioxide as shielding gas.

____ MIG welding with oxidizing agents in the shielding gas must use fluxes or filler material which contain deoxidizers to avoid arc harshness and considerable spatter. Also alloying ingredients may be used to assist in obtaining desired weld metal chemistry.

____ MIG welding is adaptable to all types of base metals and all welding positions. Spray arc transfer provides for highest welding speeds.

____ Defect prevention in MIG welding is primarily dependent upon obtaining the correct combination of current, filler material feed rate, and travel speed. These three variables establish the heating rate at the point of welding.

____ Fine porosity frequently occurs in MIG welding due to the difficulty of providing perfect shielding. Where such fine porosity is unacceptable, welding is performed in a chamber which has been evacuated and filled with an inert gas such as argon.

____ Submerged arc welding (SAW) uses a welding bead, bare filter wire, granular flux and an electrical power supply.

____ In the SAW process, the granular flux metals in the arc and serves as shielding, arc stabilizer, and deoxidizing and alloying agent.

____ In the SAW process, direct current reversed polarity gives greatest penetration and lowest deposition rate. Direct current straight polarity gives lowest penetration and highest deposition rate. Alternating current gives penetration and deposition rate somewhere between these values.

____ The absolute value of current in the SAW process primarily affects penetration depth while the current density primarily affects deposition rate.

____ Electrode extension in the SAW process primarily affects deposition rate.

____ Arc voltage in the SAW process primarily affects bead shape and contour.

____ Travel speed in the SAW process primarily affects bead size and shape.

____ The SAW process is best suited for ferrous alloys in the flat and horizontal positions. It may employ automatic welding equipemnt in either stringer bead or weave bead modes. It has the capability of adjustment for a wide variety of penetration depths and bead size.

____ The large quantities of slag produced by SAW must be removed prior to welding the next pass.

____ The granular flux used in the SAW process must be maintained dry in order to avoid porosity and cracking.

____ Defects which may occur in the SAW process are undercut, burnthrough, incomplete fusion, weld metal cracking, underbead cracking, slag inclusion, and porosity.

MATERIALS

The following materials will be needed during visits to welding shops:

1. Welder's Goggles or Hoods (hand held face shields are ideal)
2. Temperature Measuring Devices (crayon or contact pyrometer)
3. Lab Coat or Apron or Work Clothes
4. Long Sleeves

PROCEDURES

The following procedures reinforce the information presented in this module. In performing any of these activities, students/trainees should observe the following safety precautions:

- Never look at a welding flame or electric arc without welder's goggles or hoods. (NOTE: sunglasses are inadequate to protect the eyes from the intense light from welding.)
- Wear long sleeves and either work clothes, lab coat, lab apron, or coveralls.
- Avoid stepping on hoses and cables.
- Do not touch or adjust welding equipment unless requested to do so by the instructor or tour guide.
- Do not touch pieces recently welded; they will probably be very hot.

1. Visit a welding shop employing Tungsten Inert Gas welding

   a. On initial arrival at the welding shop, the instructor or a welding shop member will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. Subsequently, students/trainees should observe tungsten inert gas welding in progress and complete Data Table 28-3-7 in accordance with this procedure.

   b. Prior to reviewing the corresponding welding procedure, complete steps c, d, e, and f. Use Table 28-3-10 for additional guidance.

   c. Trace the electrical cable from the TIG torch to the power supply. Complete Section A of Data Table 28-3-7, based on observation of power supply settings and instrumentation. The nameplate data should identify if high frequency starting is available.

   d. Return to the welding station and complete Section B of Data Table 28-3-1 based on observation of the welding in progress. In describing weld bead appearance include contour, surface roughness, oxidation and blend with base metal.

   e. Request to see a new electrode that has not been used and an electrode that has been used. Compare their appearance and complete Section C of Data Table 28-3-7. In describing appearance of the electrodes include shape of the arc tip, smoothness of tip and any irregularities.

   f. Trace the shielding gas hose from the torch to the gas bottle(s). Complete Section D of Data Table 28-3-7. If a mixture of gasses is being used, calculate the percentage flow of each.

g. Obtain the procedure that represents the TIG process observed in steps c through f.

h. Compare entries on Data Table 28-3-7 with procedural requirements and list in Section E of Data Table 28-3-7 any differences and potential effects of such differences.

i. Determine for each difference if the potential effect is actually occurring and, if not, offer rationale for why not. Record your determination under the column "actual result" in Section E of Table 28-3-7.

2. Visit a welding shop employing Metal Inert Gas welding

a. On initial arrival at the welding shop, the instructor or welding shop member will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. subsequently, each student/trainee should observe metal inert gas welding in progress and complete Data Table 28-3-8 in accordance with this procedure.

b. Obtain the procedure that corresponds with the MIG welding to be subsequently observed and complete Section A of Data Table 28-3-8 from the procedural requirements.

c. Observe MIG welding represented by the procedure and check for compliance with each entry in Section A of Data Table 28-3-8. Use Table 28-3-10 for additional guidance.

d. Observe the MIG arc and determine the type of metal transfer. Record observations in Section C of Data Table 28-3-8.

e. Observe the weld in the welding condition of any pass and complete Section D of Data Table 28-3-8.

f. Review the entries in Section D of Data Table 28-3-8. Entries in the left hand column indicate ideal conditions. Entries in the middle column are less ideal but probably acceptable. Entries in the right hand column are probably unacceptable. For any entries in the right hand column, determine what could be done to eliminate the condition and describe your determination in Section E of Data Table 28-3-8.

3. Visit a welding shop employing Submerged Arc Welding

a. On initial arrival at the welding shop, the instructor or a member of the welding shop will probably guide the students/trainees on a tour of the shop and explain pertinent safety rules to be observed. Subsequently, students/trainees should observe submerged arc welding in progress and complete Data Table 28-3-9 in accordance with this procedure.

b. Obtain the welding procedure that corresponds with the submerged arc welding to be subsequently observed and complete Section A of Data Table 28-3-9 from the procedural requirements.

c. Observe submerged arc welding represented by the procedure and check for compliance with each entry in Section A of Data Table 28-3-9. List any noncompliance in Section B.

d. Observe the removal of slag and visually inspect the weld bead. Complete Section C of Data Table 28-3-9.

e. Review the entries in Section C of Data Table 28-3-9. Entries in the left hand column indicate ideal conditions. Entries in the middle column are less ideal but probably acceptable. Entries

in the right hand column are probably unacceptable. For any entries in the right hand column, determine what cound be done to eliminate the condition and describe your determination in Section D of Data Table 28-3-9.

DATA TABLE

Table 28-3-7

Tungsten Inert Gas Welding Data

A. Welding Power Supply Data

Type of Current (AC or DC)_____

Polarity_____ Amperage_____

Voltage_____ High Frequency (yes/no)_____

B. Welding Station Data

Sketch the weld joint:

Position_____ Single or Multi-Pass_____

Pass Being Welded_____ Backing_____

Filler Material

Size and Type_____

Base Metal Type_____

Preheat Temperature_____ Interpass Temperature_____

Appearance of Weld Bead_____

C. Electrode Data

Type_____ Diameter_____

Appearance Prior to Welding_____

_____

Appearance After Welding_____

_____

Would the used electrode cause problems if used again? Why?

D. Shielding Data

	Gas No. 1	Gas No. 2
Type	_____	_____
Pressure	_____	_____
Flow	_____	_____
Percentage Flow	_____	_____

E. Comparison with Procedure

Differences	Potential Effect	Actual Result

Table 28-3-8

Metal Inert Gas Welding Data

A. Procedural Requirements:

Base Material _____

Welding Process _____

Manual or Machine _____

Position _____

Filler Material Type and Size _____

Shielding Gas Type _____ Flow _____

Single or Multiple Pass _____

Single or Multiple Arc _____

Current Type (AC or DC) _____ Polarity _____

Oscillation Settings _____

Welding Progression _____

Root Treatment _____

Minimum Preheat Temperature _____

Maximum Interpass Temperature _____

Post Weld Heat Treatment _____

Cleaning Method _____

Welding Data:

PASS NO.	ELECTRODE SIZE	AMPERES	VOLTS	TRAVEL SPEED	SKETCH JOINT DETAIL

B. Differences between requirements and practice.

Requirements Not Met	Actual Practice
_____	_____
_____	_____
_____	_____

C. Check the type of metal transfer and describe the observations which led to this determination

Type	Basis
___Spray Arc	
___Globular	
___Short Circuiting	

D. As-welded condition (check observed condition).

Bead Contour	___Convex	___Flat	___Concave
Bead Surface	___Almost Smooth	___Rippled	___Bumpy
Toe	___Blended	___Slight Crevice	___Undercut
Oxidation	___None	___Slight Film	___Loose Oxides
Bead Progression	___Straight	___Slightly Crooked	___Misaligned
Spatter	___None	___Little	___Much

E. Determination on As-Welded Condition.

Unacceptable Condition	How Condition Could be Eliminated

Table 28-3-9

Submerged Arc Welding Data

A. Procedure Requirements:

Base Material _____

Welding Process _____

Manual or Machine _____

Position _____

Filler Material Type and Size _____

Flux Composition _____

Single or Multiple Pass _____

Single or Multiple Arc _____

Current Type (AC or DC) _____ Polarity _____

Oscillation Settings _____

Welding Progression _____

Root Treatment _____

Minimum Preheat Temperature _____

Maximum Interpass Temperature _____

Post Weld Heat Treatment _____

Cleaning Method _____

Welding Data:

PASS NO.	ELECTRODE SIZE	AMPERES	VOLTS	TRAVEL SPEED	SKETCH THE WELD JOINT

B. Differences between requirements and practice.

Requirements Not Met	Actual Practice

C. Slag removal and bead appearance.

Method of Slag Removal _____

All Slag Removed ____ Yes ____ No

Appearance of Bead.

Contour	____	Convex	____	Flat	____	Concave
Surface	____	Smooth	____	Rippled	____	Bumpy
Toe	____	Blended	____	Undercut	____	Rolled Over
Oxidation	____	None	____	Slight Film	____	Loose Oxides
Progression	____	Straight	____	Slightly Crooked	____	Misaligned
Spatter	____	None	____	Little	____	Much
Stop Crater	____	Filled	____	Concave	____	Cracked

D. Determination on As-Welded Condition.

Unacceptable Condition	How Condition Could be Eliminated

Table 28-3-10
Methods of Checking Welding Requirements

Type of Requirement	Method of Checking
Joint design and fit	Compare sketch or drawing referenced by welding procedure to the physical configuration of the weld joint. Measure required dimensions with mechanical measuring devices
Base metal identification (including backing)	Compare marking on base metal with welding procedure requirements. If unmarked, compare material issue record entries with weld procedure requirements.
Filler material identification	Compare marking on filler material and physical appearance and size of filler material with weld procedure requirements.
Welding position	Compare physical position of weld joint to weld procedure requirement.
Cleanliness	Visually observe for scale, oxides, dirt, oil, etc; compare with welding procedure requirements.
Preheat and interpass temperatures	For preheat, measure base material temperature within one inch of the weld joint with temperature indicating device (e.g. temperature melting crayons, contact pyrometer, thermocouple). For interpass temperature, measure the weld joint temperature immediately prior to commencement of welding.
Gas Pressure	Compare gas pressure meter readings with weld procedure requirements.
Gas Flow	Compare gas flow meter readings with weld procedure requirement.
Nature of gas (acetylene flame)	Visually observe flame through welder's goggles or hood; compare with weld procedure requirement.
Welder's technique (bead, forehand, backhand of electrode, progression, interpass cleaning, grinding, back gouging)	Visually observe the welder's practices; compare with welding procedure requirements.
Current type and polarity	Observe switch settings on the electrical power supply for AC-DC and straight-reversal; compare with welding procedure requirements.
Current	Read value on ammeter on power supply or clamp type ammeter around one cable and read value (NOTE: welding must be in progress to read current or voltage); compare with welding procedure requirements.
Post weld heat treatment	Compare time-temperature chart with welding procedure requirement. Ensure the chart represents the weld joint being checked.

REFERENCE MATERIALS

AWS, Welding Handbook, Section Two, Welding Processes, American Welding Society, Miami, Florida 33125, 1969

ASME, Boiler and Pressure Vessel Code, Section III, Nuclear Power Plant Components, The American Society of Mechanical Engineers, New York, New York 10017, 1978

ASME Boiler and Pressure Vessel Code, Section IX, Welding and Brazing Qualifications, The American Society of Mechanical Engineers, New York, New York 10017, 1978

AWS, D1.1, Structural Welding Code, American Welding Society, Miami, Florida 33125, 1977

AWS, D1.2, Commentary on Structural Welding Code, American Welding Society, Miami, Florida 33125, 1977

AWS, Metals Handbook, Volume 6, Welding and Brazing, American Society for Metals, Metals Park, Ohio, 1971

TEST

Enter the apparatus that performs the function for the tungsten inert gas process:

FUNCTION	APPARATUS
1. Directs current to the electrode and channels shielding gas around electrode.	_____
2. Encircles electrode at arc end to channel shielding gas flow 360° around electrode.	_____
3. Nonconsumable electrode that has electron emissivity properties to support an arc.	_____

List the probable result if the condition is encountered in tungsten inert gas welding.

CONDITION	PROBABLE RESULT
4. Shielding gas flow drops from 15 cubic feet per hour (cfh) to 3 cfh due to pinched gas hose.	_____ _____
5. Procedure has been established for maximum current that will give satisfactory weld with direct current straight polarity. Welder complies with procedure except reversed polarity is inadvertently used.	_____

6. In welding the root pass_____ of a v-groove joint, the included angle is so small the torch does not gain sufficient access to the root.

Circle the number of each application where tungsten inert gas welding represents the best choice of welding processes.

7. Groove joint is 3 inch carbon steel plate in flat position.
8. Groove joint is light gauge sheet metal in vertical position.
9. Root pass in grooved joint of one inch pipe where metalic backing is not permitted.
10. Grooved tee joint in main steel girders for the auxilliary equipment building.

Name the function(s) of the apparatus for metal inert gas welding.

APPARATUS	FUNCTION
11. motorized wire feeder with voltage sensor	a._____ b._____
12. argon	a._____
13. spooled bare wire	a._____ b._____
14. flux in flux cored wire	a._____ b._____
15. constant voltage power supply	a._____ b._____

List the potential effect on weld quality if the condition occurs in metal inert gas welding.

CONDITION	EFFECT
16. spray arc welding where current is lowered below transition current value.	
17. Use of argon and 5% oxygen shielding with filler wire that is non-deoxidizing	
18. Failure to establish pre-heat prior to spray arc welding of low alloy steel.	

Classify the statement as true or false for metal inert gas welding.

19. Spray arc is best suited for the overhead position. _____

20. Spray arc offers high welding speeds in the flat position. _____

21. Wire speeds and deposition rates are compatible. _____

22. Most shallow penetration occurs with short circuiting metal transfer. _____

23. Deepest penetration occurs with spray arc metal transfer using direct current reversed polarity. _____

Name the function(s) of the apparatus for submerged arc welding:

APPARATUS	FUNCTION
24. granular flux	a.
	b.
	c.
25. spooled bare wire	a.
	b.

Name the primary cause of the weld condition for submerged arc welding.

CONDITION	PRIMARY CAUSE
26. broad, flat bead that rolls over	
27. narrow, bumpy bead	
28. burnthrough	
29. slag inclusion	
30. non-overlapping weave beads and incomplete fusion between weave beads	

Classify the statement as true or false for the submerged arc welding process.

31. Extremely high welding speeds are obtainable in the flat position.
32. Deposition rate is a function of electrode extension past the welding head nozzle assembly.
33. Loss of argon flow causes porosity.
34. A wide range in penetration can be obtained by adjusting current, feed rate, and electrode extension.